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ANALYSIS OF FIELD TESTS COMPARING SECOND AND THIRD GENERATION IMAGE INTENSIFIERS

by

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A recent analysis of one of the field tests provided strong evidence that a predominance of artificial light from nearby areas contaminated the site. The effects of such contamination—not representative of a wartime blackout environment—were analyzed showing that GEN2 and GEN3 performance tended toward equality as the relative amount of artificial light contamination increased.

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PREFACE

The field test conditions for the comparison of the third generation (GEN3) image intensifier to that of the second generation (GEN2) have never been adequately characterized. Although test results have been reported from ANVIS (AN/AVS-6) and AN/PVS-7 development test/operational test (DT/OT) II, Driver's Viewer (AN/VVS-2) OT I, and tests conducted by the Visionics Division of the Center for Night Vision and Electro-Optics (CNVEO), no analysis of test conditions, especially the scene light level, has ever been reported.

The connotation of the term "light level" as reported in these tests has become seriously misleading and not well recognized by the night vision intensifier community. A review of all intensifier field tests showed that where light level was reported, it was measured and expressed in units of foot-candles (fc), having no meaning at all when the available night sky power level for GEN2 or GEN3 systems analysis was a primary concern. Foot-candle, the photopic unit of measure, only has meaning when the human eye is the sole detector of concern, and only measures the apparent brightness to the human eye. It gives no indication of power level or power distribution of the field light conditions.

The photopic (foot-candle) measure and reporting of field test illumination conditions, as related to comparative testing of any nonphotopic sensor (such as GEN2 or GEN3 intensifier systems), have produced widespread misinterpretation of the test results and have promulgated a *false* presumption that the comparative tests were performed under the same conditions.

A recent analysis of one of the field tests provided strong evidence that a predominance of artificial light from nearby areas contaminated the site. The effects of such contamination—not representative of a wartime blackout environment—were analyzed showing that GEN2 and GEN3 performance tended toward equality as the relative amount of artificial light contamination increased.

Evidence that such contamination existed was supported by the analysis of the combined factors of field meteorological conditions and photopic light levels as monitored during all nights of the test. Test results indicated near equal range performance of GEN2 and GEN3 systems. Based on the analysis, an absence of artificial light contamination would have resulted in a higher range performance factor for the GEN3 system of up to 1.7 times that of the GEN2 system. Artificial light contamination makes these and other test results undecipherable for anyone trying to make a valid assessment of the relative merits of GEN2 or GEN3 intensifier technology.

Besides range performance, other tasks commonly used for performance evaluations at DT/OT are measured by time to perform each task. The methodology of these techniques, however, does not provide the necessary information for assessing the merits of GEN2 versus GEN3 technology differences. To provide a viable test basis on which to assess the performance differences between the technologies, the test results should present the light level at which the proficiency in performing the task begins to decline, and the light level threshold where the task can no longer be performed. In these cases, light level must be measured in terms of relative radiant power available across the spectral sensitivity band of the GEN2 or GEN3 detector.

In all cases, radiometric (not *photometric*) light level measurements are necessary to avoid the confusion and misinterpretation of test conditions.

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SECTION I. INTRODUCTION

Field tests conducted over the past several years compared the performance of second generation (GEN2) and third generation (GEN3) image intensifier systems. These tests included the ANVIS (AN/AVS-6) and AN/PVS-7 DT/OT II and the Driver's Viewer (AN/VVS-2) OT I. A 1986 Army Material Systems Analysis Agency (AMSAA) report[1] summarized the test results, including those developed by the Visionics Division of the Center for Night Vision and Electro-Optics (CNVEO). This AMSAA Report failed to address test conditions, particularly illumination or, more importantly, scene irradiance.

Scene illumination levels were measured in photometric units—foot-candles (fc)—in these tests. Such units were developed for the specific purpose of measuring the visual response of the human eye. For example, given a 1fc illumination can be said to have the same apparent brightness to the human eye as any other given 1fc illumination, although no conclusions can be drawn about the power level, spectral distribution, or color of these two given illuminations. Simply stated, a 1fc brightness can be obtained from light that is all green, red, blue or innumerable combinations of rainbow colors. Confusion and misinterpretation results from the use of photometric units when used to characterize the interaction of light with sensors other than the human eye. This difficulty immediately arises when attempting to use photopic units to determine the radiant signal level available to an image intensifier. Lucien Biberman, Institute for Defense Analysis, observed that:

> *The confusion between 'light' as that which produces the sensation of vision at the retina, and light as exemplified by the radiant power that makes grass grow, exposes photographic film, or activates a television camera (or image intensifier) is all but hopeless.*[2]

The confusion which Biberman refers to remains a problem especially in discussing the use and operation of image intensifier systems. The general belief that a *lumen is a lumen*[2] has distorted the reporting of true test conditions and caused test evaluators to draw erroneous conclusions from the results, with serious implications for decision makers who decide upon procurement and deployment on the basis of such data.

Understanding how the image tube performance parameters and the effective illumination conditions are defined and reported in field tests is the key to understanding the differences between GEN2 and GEN3 image intensifiers. This involves broad issues such as the units of measure discussed above, as well as specific test characteristics such as the effects of artificial lights from nearby cities on the general test environment and on the specific performance of GEN2 and GEN3 image intensifier systems. The CNVEO's Blossom Point, MD, test, conducted in the summer of 1984, collected data on system performance which is analyzed in this report and used to illustrate principal points. The Blossom Point test is the only field test for which reasonably complete meteorological data is available, although only photometric light level readings were collected. This analysis examines the environmental and operational conditions for field tests necessary to determine baseline performance differences between GEN2 and GEN3 image intensifiers. These baseline performance differences are defined for conditions when the night sky was the only source of illumination and blackout conditions were assumed. These conditions are assumed to exist prior to military engagement. After military engagement begins, various sources of artificial illumination will be scattered about the battlefield including flares, fires, tracers, etc. This is the subject of another analysis.

While thermal imaging systems operate by sensing the heat energy radiated from a scene and measuring the temperature difference between an object and its background, image intensifiers operate by virtue of illumination from natural or certified sources being reflected from the target and background being observed.

Figure 1 depicts the typical use and operation of an image intensifier system. The scene to be viewed reflects the ambient light. A fraction of this reflected light is collected by the system's objective lens and focused onto the photocathode. Here, a portion of the light power interacts with the photocathode, releasing electrons and generating signal current. This current is then amplified by the microchannel plate (MCP) through an electron multiplication process. Electrons released by the MCP are accelerated towards the phosphor screen where there kinetic energy is converted into visible light, creating an intensified image of the scene. The intensified image can then be viewed through an eyepiece.

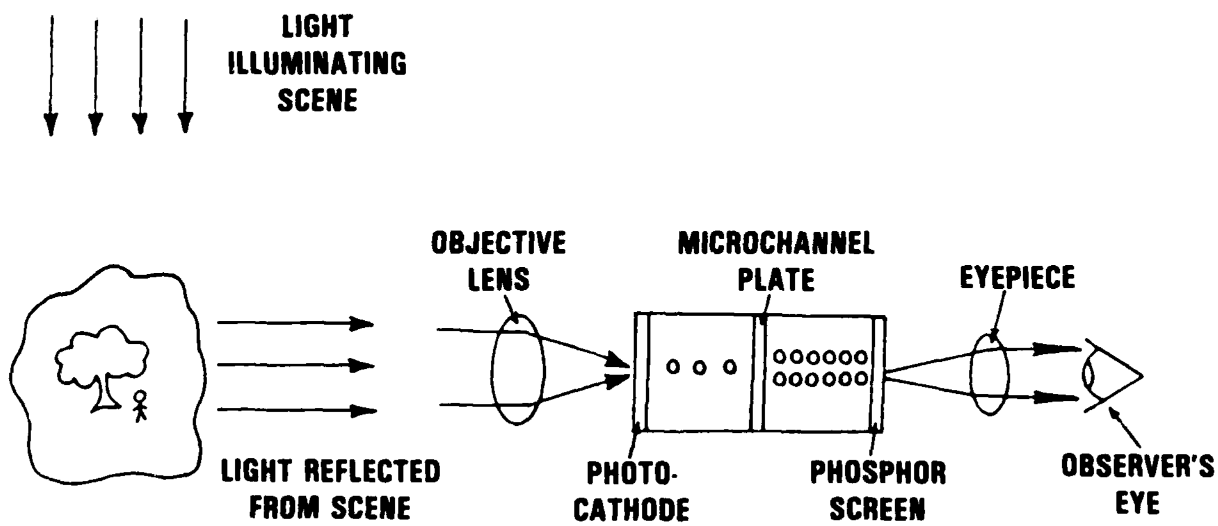


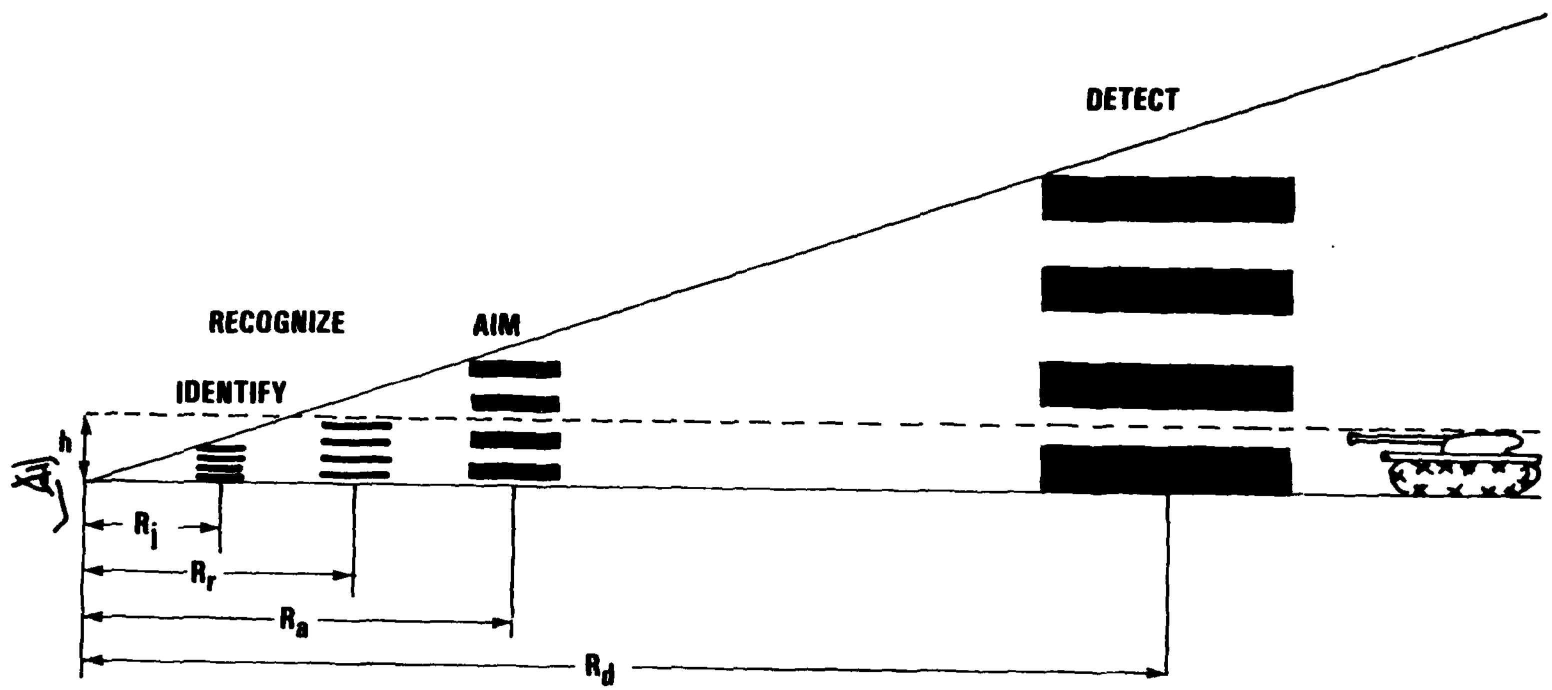
Figure 1. Operation of Image Intensifier

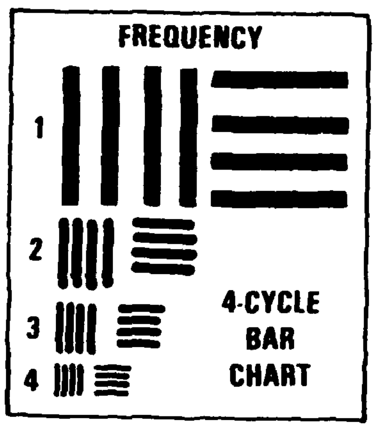
In considering this physical process, the following questions arise which must be addressed: (1) How clearly can a scene be viewed through an image intensifier, or stated differently, what are the limitations to the resolution of detail in the scene? (2) To what extent are clarity and resolution of detail required to perform specific tasks? Question (1) relates to clarity as a scene illumination function and the specific scene characteristics such as spectral reflectivity, as well as the spectral and spacial parameters of the image intensifier itself. These issues are discussed in Section II.

Particular answers to Question (2) depend upon the function and application of the image intensifier, whether it is being used for:

- Detecting, recognizing, or identifying targets
- Driving various vehicles
- Helicopter pilotage
- Maintaining vehicles and weapons
- Firing weapons
- Medical aid
- Walking
- General orientation.

Answers to this question will be different for each task. More detailed information is required to recognize a target than to merely detect it (Figure 2). Similarly, driving a vehicle on a familiar highway is quite different from driving safely on an unfamiliar unpaved road. On the other hand, an experienced mechanic can change a tire with the same efficiency with almost any amount of light without the aid of a night vision device. Nevertheless, tasks upon which DT/OT are based (Table 1) generally require some degree of image clarity and resolution of detail, unless they can be performed in total darkness.





$$\text{RESOLVABLE FREQUENCY} \times \frac{h}{R} = \text{NO. OF RESOLVABLE CYCLES } N$$

$$\text{RESOLUTION} = (\text{RESOLVABLE FREQUENCY})^{-1}$$

TASK	N
DETECT	1.0
AIM	2.5
RECOGNIZE	4.0
IDENTIFY	8.0

Figure 2. Detection and Identification of Targets

Table 1. Tasks Performed at DT/OT (Ground Systems)

TASK	MEASUREMENT OF EFFICIENCY
Disassemble Rifle	Time
Assemble Rifle	Time
Treat Injuries	Time
Change Fuel Pump	Time
Change Fan Belt on Armored Personnel Carrier (APC)	Time
Mounted Movement	Time
Put Radio into Operation	Time
Lay Telephone Wire	Time
Emplace Claymore Mines	Time
Change Truck Tire	Time
Run Obstacle Course	Time
Driving Accuracy	Number of pylons knocked down
Weapon Firing	Number of hits
Landolt C Test	Range
Target Detection	Range

Image clarity and the extent to which detail can be resolved vary with changes in light level. As the level of light decreases, a point is reached when task performance efficiency decreases until the task is no longer possible. The light level at which this performance threshold occurs is different for GEN2 and GEN3 image intensifiers. If the light level is higher than when efficiency decrease becomes noticeable, any further increase in light level will not increase the efficiency of task performance. The differences observed at these light levels are *system*—and not technology—*dependent*.

For example, changing a fan belt on an Armored Personnel Carrier (APC) is a task quite frequently performed in DT/OT testing. First, consider performing this during the daytime without a night vision aid. An operator can perform this task with the same efficiency regardless of whether the day is clear and sunny, heavily overcast or twilight, as long as he can clearly distinguish the details for changing the belt. In other words, light level changes of several orders of magnitude do not change operator efficiency in task performance.

Trouble starts when the operator can no longer distinguish the critical features required to change the belt. He will still perform the task using his sense of touch rather than sight, but his trial-and-error operations will prolong the time from start to finish. Once it becomes so dark that he can no longer see the components, he is effectively blind. There is no basic difference in performing the same task while wearing a night vision aid. The differences initially encountered are system-related such as shallower depth of field, narrower field of view, and the discomfort from wearing a relatively heavy system protruding several inches in front of the operator's face. He will, however, experience the same changes in performance efficiency at light levels. Starting at a relatively high light level (e.g., full moon), his efficiency will not decrease with decreasing light levels until he cannot distinguish his equipment and tools. He will then go through a period of decreasing efficiency until it gets too dark to perform the task. The light level at which this period of decreasing efficiency starts and that level at which it gets too dark to perform the task at all while using a GEN2 or GEN3 night vision device has never been tested.

During the past DT/OT comparing the GEN2 AN/PVS-5 and the GEN3 AN/PVS-7, the tests for efficiency to perform these tasks were done in the field under whatever ambient illumination level existed. It should not be surprising, therefore, that no significant differences were observed. Also, with sufficient training, some of the DT/OT can be performed by touch only and with no illumination. The only meaningful way to ascertain the differences in performing various tasks while utilizing a GEN2 or GEN3 image intensifier is by performing the task at varying light levels in order to find the point of declining efficiency and the light level threshold where the task can no longer be performed.

Tests like these are certainly difficult to perform in the field since light levels cannot be controlled. However, many of the tasks can be performed in an enclosed environment where night sky illumination is simulated. Where field test comparisons of GEN2 and GEN3 image intensifiers are being conducted, it would be most informative to perform these tasks at the illumination conditions where the differences would most likely occur—clear starlight and overcast starlight. The tests should be conducted under both illumination conditions, because a clear starlight level might still be too high for some tasks to be in the range of declining efficiency. For other tasks, overcast starlight might be too dark for both types of image intensifiers. If a specific task can be performed with the same efficiency by both systems under an overcast starlight condition, it can be assumed that the technology utilized does not make a difference under any condition.

These tests are required to obtain any meaningful quantitative data on basic differences between GEN2 and GEN3 image intensifiers, where the differences in time required to perform those tasks is a measure of efficiency. Driving exercises should also be evaluated in these tests. For fair technology comparison testing, system-related differences should not be present in order to avoid distorting the results of intensifier tube comparison testing. The only difference should be the use of a GEN2 or GEN3 image intensifier tube in a given system. Furthermore, it should be recognized that some of the tasks performed at DT/OT testings will show no differences in efficiency down to the lowest light levels generally encountered, independent of the generation of the intensifier, but dependent only on prior experiences.

SECTION II. PARAMETERS AFFECTING IMAGE INTENSIFIER PERFORMANCE

The only way to determine the differences in efficiency while performing the tasks with a GEN2 or GEN3 device is to perform the same task at various light levels. The reason is to determine the light level at which the period of declining efficiency starts. It is difficult to get consistent field conditions to evaluate the degradation in efficiency of GEN2 or GEN3. One task where sufficient test data was available and theoretical performance calculations can be made based on illumination. scene, and intensifier parameters is the detection, recognition, and identification of targets.

The following qualitative discussion emphasizes those parameters and conditions that result in performance differences between GEN2 and GEN3 devices. For more complete quantitative treatment, refer to references [3] through [6].

The following assumptions are made for this discussion:

1. The light level is starlight or lower illumination levels. On moonlit nights, small differences between GEN2 and GEN3 devices may be expected.

2. The image size of the target at the intensifier is large compared to the resolution limit of the device. This can be expected for the light levels considered. For images which are large compared to the resolution limit, contrast reductions caused by either system will be small. Since the intent of this report is to determine changes in detection ranges due to the technology utilized, contrast reductions caused by the degradation in system optical performance are disregarded.

3. For the light levels assumed and the 40-degree field of view of the systems under consideration, detection ranges up to several hundred meters are expected. Except when fog or smoke is present, atmospheric attenuation and scattering effects will be small and differences in these effects for the two technologies are considered negligible. Fog and smoke effects are not considered in this report.

4. The target-to-background contrast is assumed to be equal; however, for some of the given target-to-background scenarios, the contrast values are larger for GEN2 image intensifiers. For others, values are larger for GEN3 image intensifiers (see Table 2). Where very precise analysis is desired or required, actual contrast values should be used for each study case.

Table 2. Contrast Values for Various Systems, Targets, and Backgrounds for Clear Starlight Illumination

SYSTEM	TARGET	GREEN GRASS	DEAD GRASS	DRY ROAD	GREEN FOLIAGE	LONG NEEDLE PINES	SAND	AVERAGE CONTRAST
GEN2	Soldier in fatigues	44	39	57	50	23	47	43
GEN3	Soldier in fatigues	49	28	49	56	35	33	42
Eyeball	Soldier in fatigues	24	57	70	18	91	69	55
GEN2	O.D. paint	9	1	31	19	24	14	16
GEN3	O.D. paint	7	30	8	21	19	21	18
Eyeball	O.D. paint	27	59	71	21	84	70	55
GEN2	Camouflage paint	4	5	27	15	31	10	15
GEN3	Camouflage paint	4	34	5	15	23	25	18
Eyeball	Camouflage paint	6	47	63	1	95	62	45

5. All system and tube parameters are chosen to be identical with the exception of generation unique parameters; e.g., photocathode sensitivity and the noise figure (noise due to the electron multiplication process). This assumption encompasses the new AN/PVS-7 designed to accept GEN2 as well as GEN3 image intensifiers. System-unique parameters are taken into consideration wl.en the Blossom Point test results are analyzed later in this report.

The threshold for target detection is directly proportional to the difference in brightness between the target and the background, divided by the fluctuation in the brightness as measured at the output phosphor screen. This ratio is called the signal-to-noise (S/N) ratio. Target and background area are assumed to be equal. The output brightness is proportional to the current generated at the photocathode, and the S/N ratio is proportional to the square root of this current divided by the noise figure. The signal current is defined as the larger of the currents generated over the area of the image of the target or an area of the background of equal size surrounding the target. Since the target-to-background contrast is assumed to be the same when viewed through a GEN2 or GEN3 image intensifier, the limits for target detection can be reformulated to read: the threshold for target detection is proportional to the S/N ratio at the output phosphor screen, as given by the square root of the signal current divided by the noise figure.

$$S/N = \sqrt{\frac{\frac{I}{2e\Delta f}}{N_f}}$$

where:

I = average cathode current
Δf = measurement of noise equivalent bandwidth
e = electron charge constant
N_f = noise figure

In cases where differences in contrast have to be taken into account, the S/N ratios have to be multiplied by the factor $C \times \sqrt{2/1+C}$, where C is the absolute value of the contrast at the phosphor screen.

$$C = \frac{B - B2}{B1 + B2}$$

B1 = Brightness in target area
B2 = Brightness in background area

As an observer moves away from a target, the area of the target's image at the photocathode (and with it the signal current) decreases proportionally to the square of the distance between the target and the observer; thus, the S/N ratio decreases with the distance. Since the S/N ratio determines the limit of detection, the detection range is directly proportional to the S/N ratio or to the square root of the signal current. The detection range differences between GEN2 and GEN3 image intensifiers are thereby determined by the differences in their signal currents.

Before proceeding further in this analysis, an example familiar to many people will be considered that will illustrate the various possibilities for changes of the signal current and its effect. Consider a person parked in a recreational vehicle watching a football game on a black and white TV. As long as he is parked close to the TV station, he will receive a smooth, noise-free picture. Resolution of detail will be limited only by the inherent resolution of his TV set. As he drives away from the TV station, the power received by his antenna will decrease and the picture will become more and more noisy. At some point, the picture will start losing details. The viewer may still see the players on close up shots, but he will not find the ball or see the goal posts. Finally, the picture will consists of varying degrees of noise. The TV viewer will have the same experience if:

1. He is stationary but the output power of the TV station decreases.
2. The antenna's sensitivity decreases.
3. The carrier frequency (or wavelength) of the TV station changes, but the bandpass filter in his TV set stays at the same frequency (wavelength).

Viewing a scene through an image intensifier is analogous to this example. A decrease in the power of the TV station corresponds to a decrease in light level, and a decrease in the sensitivity of the antenna corresponds to a decrease in overall photocathode sensitivity.

The analogy corresponding to the third situation is not as easily understood. It is, however, precisely this third situation that causes the confusion and misinterpretation discussed in the introduction to this report. It is a well known fact that, to view a TV station, one must first have an antenna to detect the signal sent out by the station. Second, one must turn the TV set's tuner to the frequency of that station. The tuner is basically a bandpass filter. A bandpass filter has its maximum transmission of the signal at the center frequency and, as the center frequency increases, the picture becomes noisy due to the decrease in signal current, which effectively decreases the S/N ratio. In principle, the phenomena are exactly the same when the information or signal is carried by light waves and detected by a photon detector, such as the human eye or an image intensifier. The only differences are that both the detector and the bandpass filter are generally a part of the same component, the photocathode, and that the bandpass filter characteristics of the photocathode cannot be tuned. The combined effort of the detector and the bandpass filter is called the *spectral sensitivity of the detector*. Figure 3 shows the absolute spectral sensitivity (expressed in milliamperes per watt (mA/W)) of an average GEN2 and GEN3 image intensifier, and the relative spectral sensitivity of a photometer which is identical to the sensitivity of the human eye. The photometer has become the standard instrument to measure light level and, when properly calibrated,[2] gives a reading in lumens per square foot (fc) or in metric units, lumens per square meter (lux (lx)).

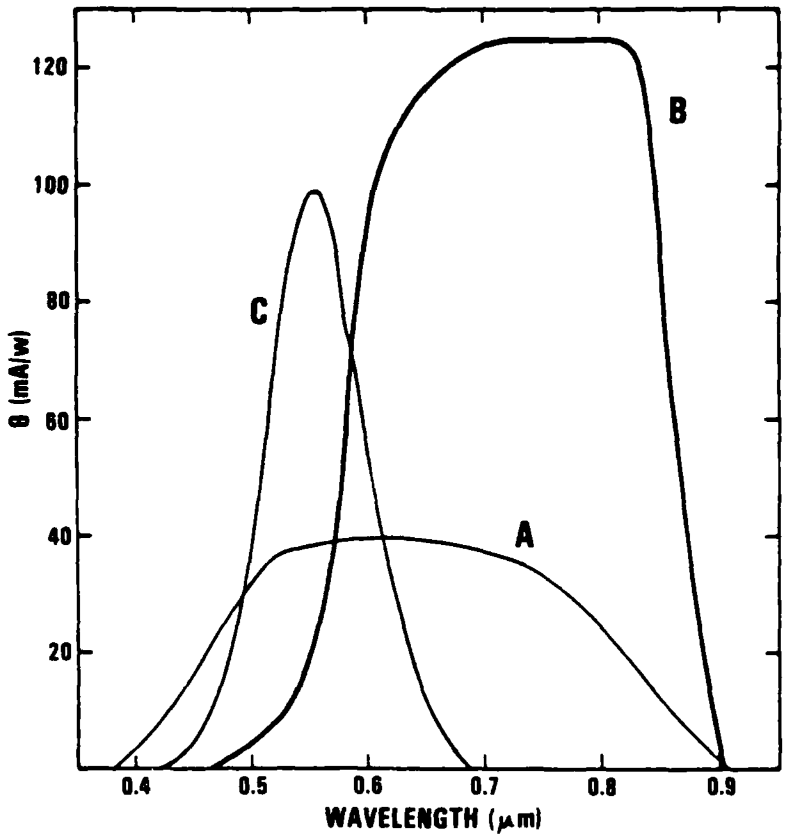


Figure 3. Spectral Sensitivity of GEN2 (A) and GEN3 (B) Image Intensifier and Relative Response of Photometer (C)

Reconsider for a moment the example of the TV station that changes its carrier frequency and creates the analogous situation for viewing a scene with the naked eye or through an image intensifier. The carrier frequency corresponds to the wavelength of the light that illuminates the scene. (Note: frequency (f) and wavelength (λ) are related by the formula $f = v/\lambda$ where v = the speed of light.) The modulations of the carrier frequency which contain the video information or the signal correspond to the intensity differences of the light caused by the differences in reflection of the different scene and target features. As we start to illuminate the scene with light at a wavelength well below 0.4 micrometer (μm) or 10^{-6} meters (m), the scene will appear totally dark for all three detectors depicted in Figure 3. The photometer will read zero fc. As we increase the wavelength of the light, while keeping its level of power (measured in watts (W)) constant, first the GEN2 intensifier, then the photometer (or human eye), and finally the GEN3 intensifier will respond by generating signal current. A maximum photopic light level, measured in fc, is obtained at the center of the bandpass filter of the photometer at about 0.55μm (green light). A further increase in wavelength will decrease the fc reading of the photometer and will reach zero close to 0.7μm. Beyond this wavelength, the photometer (or the human eye) will register zero fc, no matter what the power of the light. On the other hand, both types of image intensifiers are quite sensitive beyond 0.7μm. If, for example, the scene is illuminated at a wavelength of 0.85μm by a GaAs laser of sufficient energy, a clear picture can be obtained with both types of intensifiers at a measured light level of zero fc.

This example clearly demonstrates how meaningless the measurement of light level in units of fc can be and how easily the confusion and misinterpretation of image intensifier field test results can occur. In order to end the confusion and avoid further misinterpretation, the following rules should be strictly adhered to:

1. Fc or lx as a stand-alone unit for the measure of light level shall only be used when the human eye is the sole detector.

2. For any detector with a spectral response different from the human eye, fc or lx shall only be used when referred to a special source of illumination of known spectral distribution; for example, fc of a clear night sky based on a specific referenced distribution or fc of a standard 2856 K tungsten light source.

3. If no reference to a special source of illumination can be made, fc or lx as a unit for the measure of light level should never be used. In these cases, the unit for the measure of light level should be the spectral irradiance given in watts per square meter per micrometer bandwidth versus wavelength. This loses the convenience of a single number, but it is unavoidable. The measuring bandwidth to be used depends on the spectral response of the detector(s). For GEN2 and GEN3 image intensifiers, a bandwidth of 0.1μm is probably sufficient.

In actual field tests, the scene is normally not illuminated by a GaAs laser or any other single line light source. Figure 4 shows the illumination conditions generally encountered in field tests. The light illuminating the scene is a mixture of more or less attenuated light from the night sky, starlight, atmospheric sky glow, and reflected and scattered streetlighting. Figure 5 shows the spectral distribution of a clear night sky[7] and two commonly used streetlights.[8] The power levels or the irradiance for these sources of illumination have been normalized for the same light level measured in fc. Streetlights are designed to have most of their output power in the wavelength region where the human eye or the photometer is most sensitive. The spectral irradiance of clear starlight, however, increases sharply and is greatest beyond 0.7μm. This is the wavelength region (beyond 0.7μm) where GEN3 image intensifier is most sensitive, giving this technology the ability to capture the available higher radiation of the night sky. It is also the region where target reflections tend to be very high.

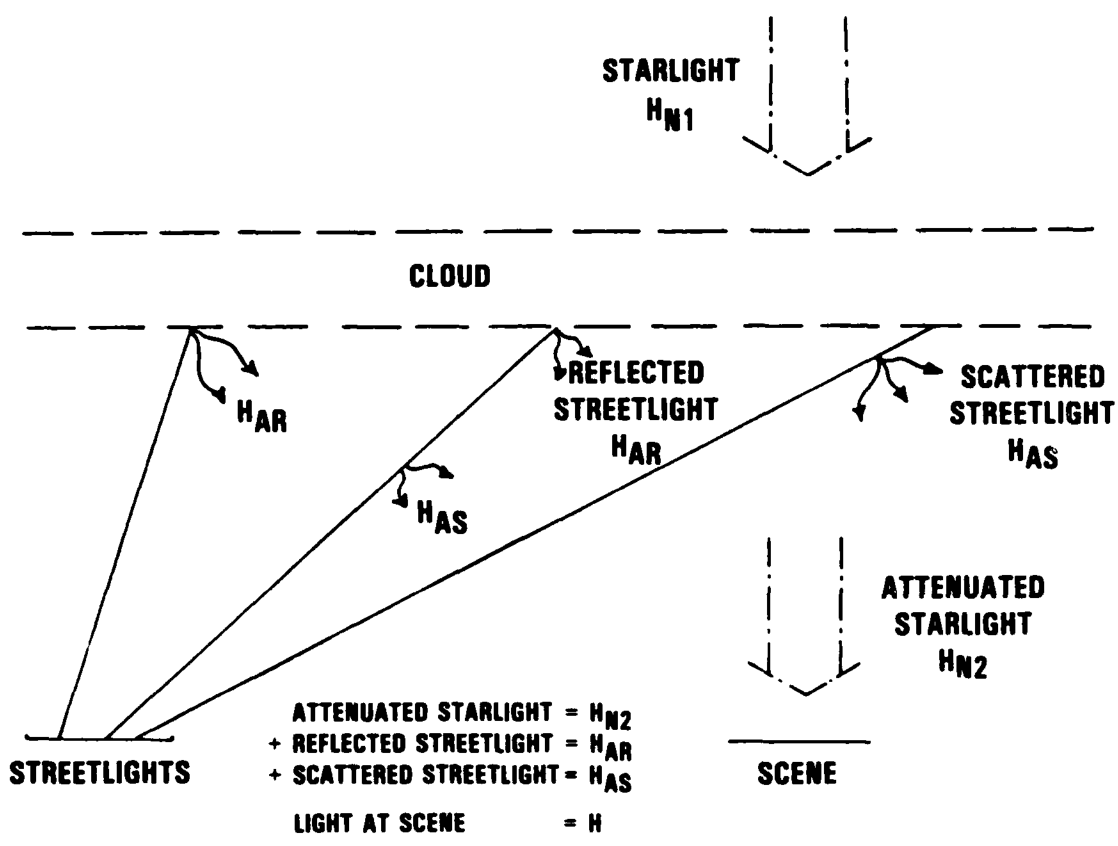


Figure 4. Illumination Conditions

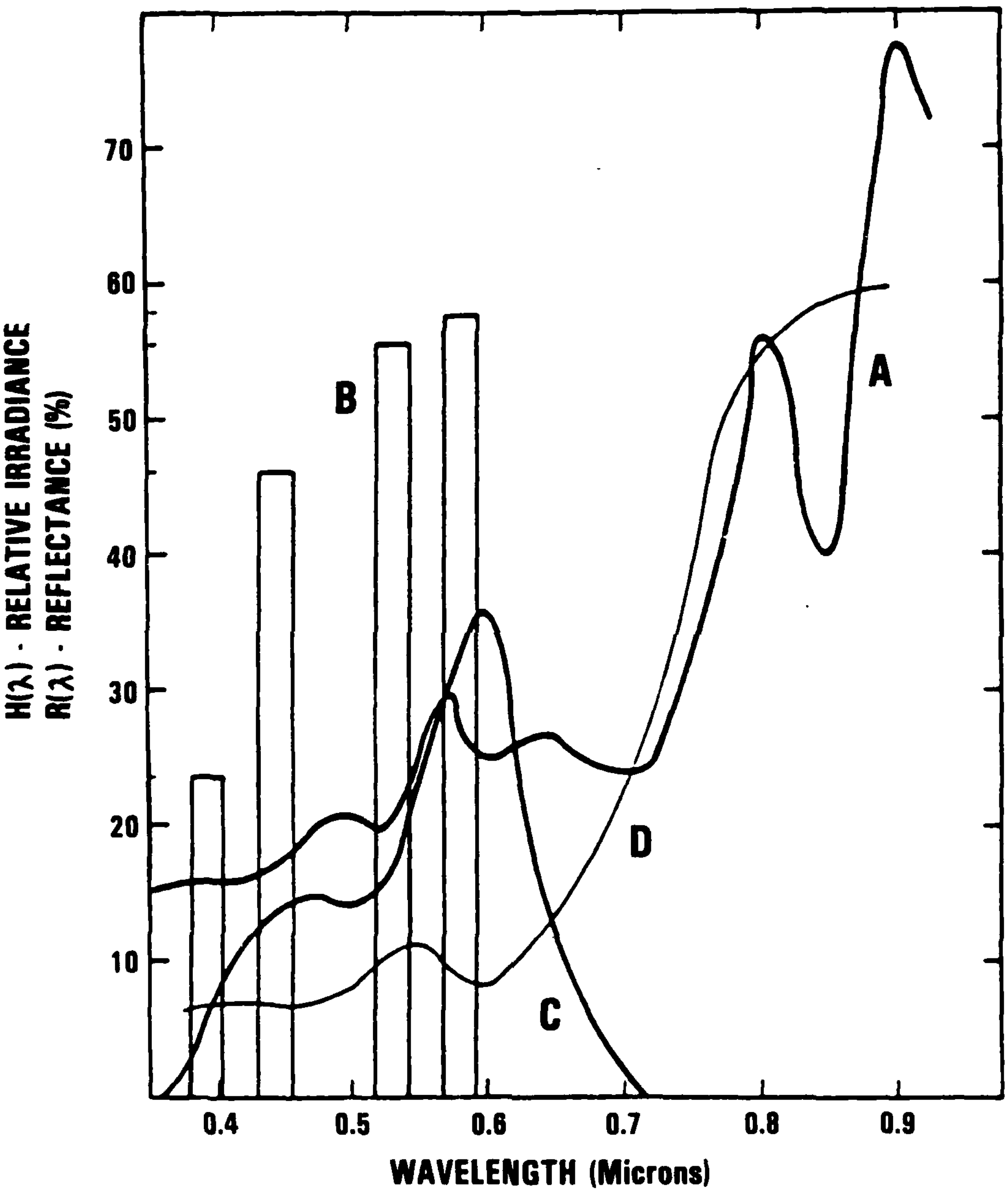


Figure 5. Spectral Irradiance Normalized to 1 Footcandle Illuminance for Night Sky (A), Mercury Lamp (B), Fluorescent Lamp (C), and Foliage Reflection (D)

In order to determine the expected performance differences between GEN2 and GEN3 image intensifiers under various illumination and irradiance conditions (including both natural and artificial sources), only the signal currents generated under these conditions need to be calculated. Under all conditions, it will be assumed that the light levels as measured in fc are identical. First, the signal current for both types of intensifiers will be calculated where the scene is illuminated with light from a mercury lamp, fluorescent lamp, or the clear night sky. The results of these calculations will illustrate the effects produced by various mixtures of these illumination sources. For considering scene reflection, two extreme cases must be addressed wherein actual scene reflection will fall between them.

Case 1. The reflection does not change with wavelength, i.e., the constant reflection case.

Case 2. The reflection changes with wavelength as shown in Figure 5, D.

Mathematically, the total signal current (l) is the area under the curve resulting from multiplication of the spectral sensitivity $\varnothing(\lambda)$, the spectral irradiance $H(\lambda)$, and the spectral reflectivity $R(\lambda)$. This may be expressed as:

$$I = \int H(\lambda)\, R(\lambda)\, \varnothing(\lambda)\, d\lambda.$$

Figures 6 and 7 show the resultant product of sensitivity, irradiance, and reflectivity as a function of *wavelength for a clear night sky and mercury lamp illumination, constant reflectance, and foliage* reflectance for GEN2 and GEN3 responses. Table 3 gives ratios of signal currents for the various conditions considered. These figures and the table demonstrate the effects produced by different types of illumination as measured by the image intensifier. The signal current may be significantly different for GEN2 and GEN3 intensifiers even though the photopic illumination levels of all the sources are identical. For these calculations, system parameters were assumed identical for the GEN2 and GEN3 image intensifiers. The analysis shows that it takes 60 times more fc of light to generate the same signal current in a GEN3 image intensifier (assuming foliage reflection) when the scene is illuminated with a mercury lamp as compared with the pure night sky. For a GEN2 image intensifier, the factor is only 9.3 under the same conditions. In other words, keeping the fc the same, but changing from night sky to mercury illumination, the GEN3 signal current will decrease by a factor of 60 whereas the GEN2 signal current will decrease by only a factor of 9.3.

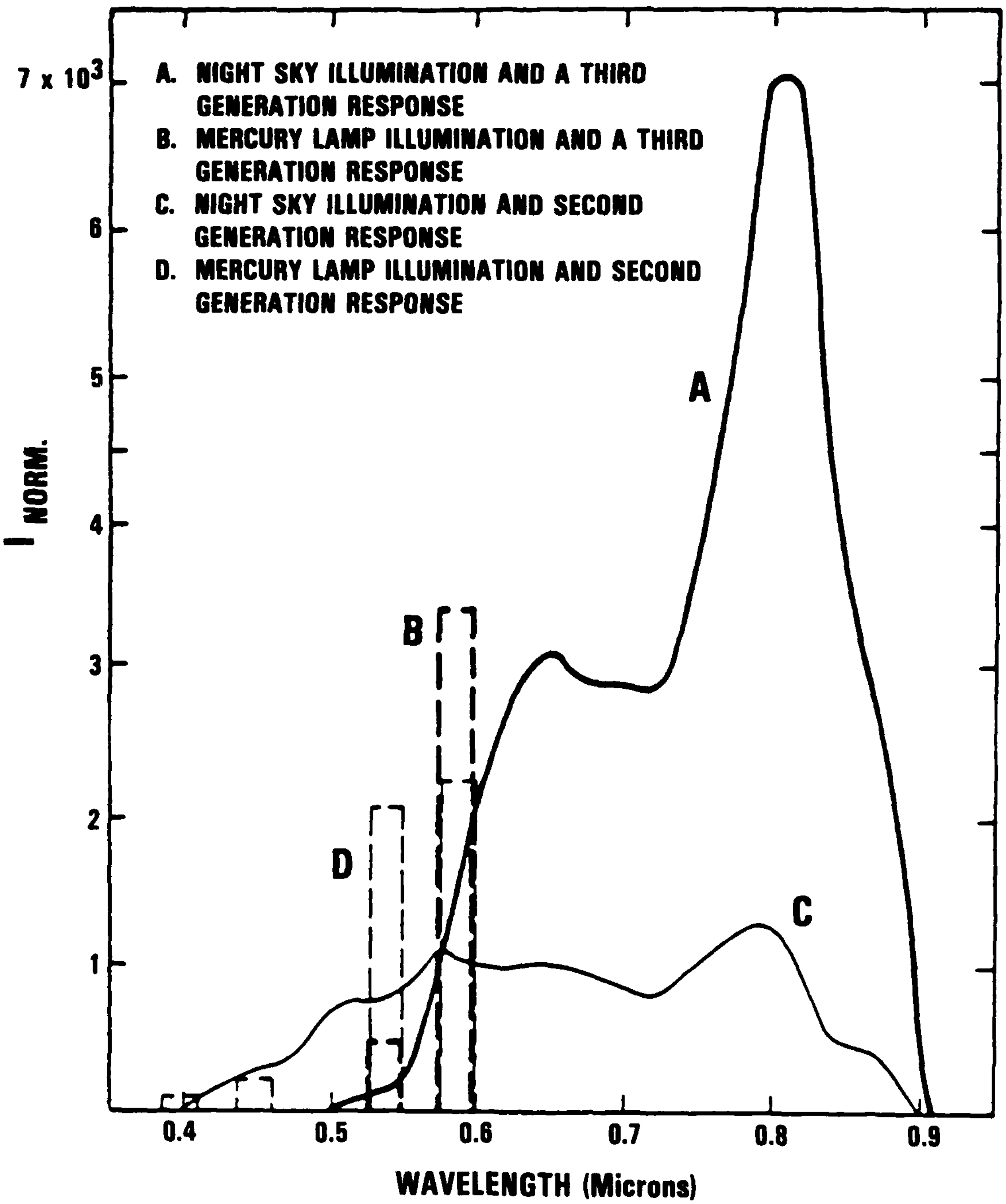


Figure 6. Cathode Current Versus Wavelength for Constant Light Level Measured in Footcandles

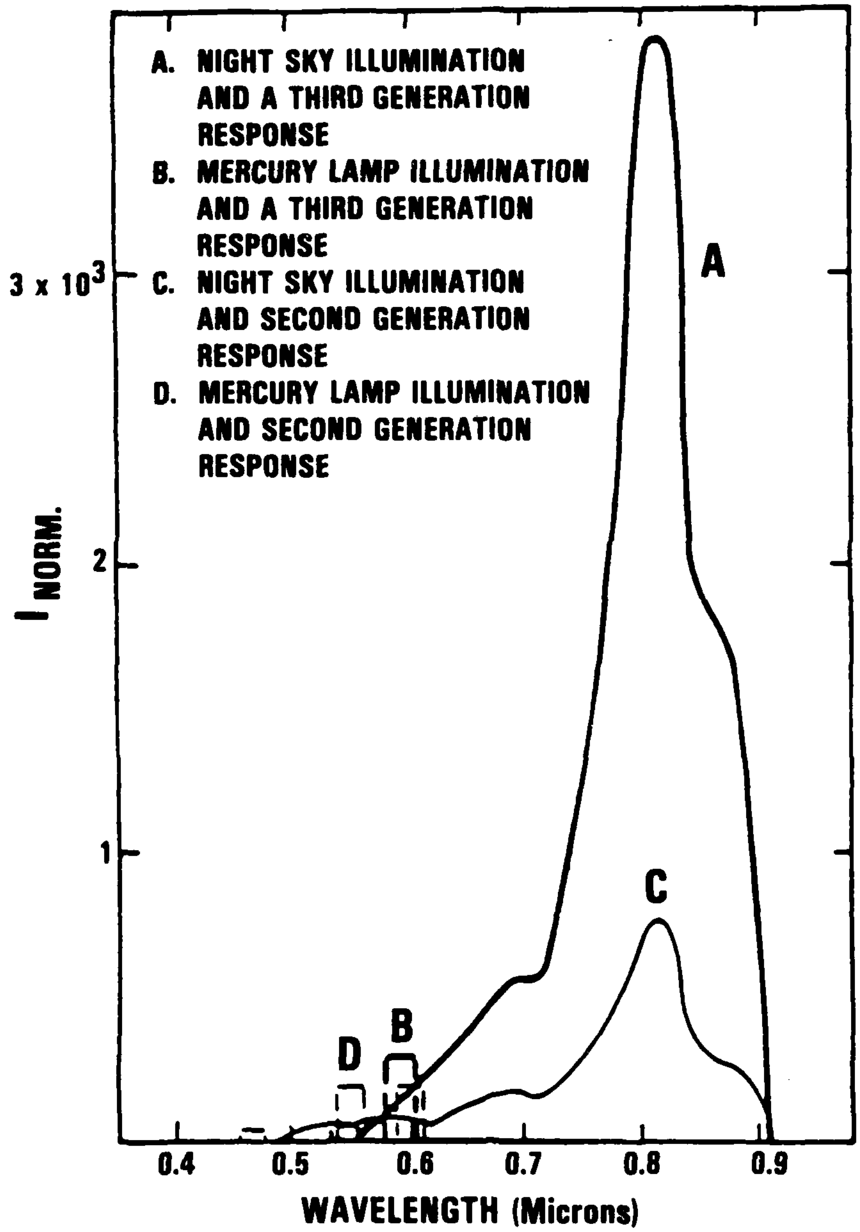


Figure 7. Cathode Current Versus Wavelength for Constant Light Level Measured in Footcandles, Foliage Reflection

Table 3. Ratios of Signal Currents for Equal Photopic Light Levels

Detector First symbol	2 = Second generation intensifier 3 = Third generation intensifier
Source of illumination Second symbol	N = Night sky F = Fluorescent lamp M = Mercury lamp
Reflection from scene Third symbol	F = Foliage reflection C = Reflection constant with wavelength
Example I(3MF)	Signal current I for 3rd generation image intensifier for light from a Mercury Lamp reflected by Foliage

$$\frac{I(3NC)}{I(2NC)} = 3.1 \qquad \frac{I(3NF)}{I(2NF)} = 4.4$$

$$\frac{I(3FC)}{I(2FC)} = 1.4 \qquad \frac{I(3FF)}{I(2FF)} = 1.4$$

$$\frac{I(3MC)}{I(2MC)} = 0.72 \qquad \frac{I(3MF)}{I(2MF)} = 0.67$$

$$\frac{I(3NC)}{I(3FC)} = 4.8 \qquad \frac{I(3NF)}{I(3FF)} = 18.5 \qquad \frac{I(3NC)}{I(3MC)} = 11.9 \qquad \frac{I(3NF)}{I(3MF)} = 60.0$$

$$\frac{I(2NC)}{I(2FC)} = 2.2 \qquad \frac{I(2NF)}{I(2FF)} = 6.0 \qquad \frac{I(2NC)}{I(2MC)} = 3.0 \qquad \frac{I(2NF)}{I(2MF)} = 9.3$$

Table 4 shows the normalized signal current of a GEN2 image intensifier and a GEN3 image intensifier for various mixtures of artificial streetlight with natural night sky illumination. For each of the different mixtures, the photometric light level measured in fc is the same. Also shown in Table 4 are the expected range increases under the assumptions previously made of the GEN3 AN/PVS-7 over the current GEN2 AN/PVS-5 and a GEN2 AN/PVS-7. For this analysis, the same system parameters for the GEN2 and GEN3 AN/PVS-7 systems were used. System parameters are shown in Table 5. The higher noise figure of the GEN3 image intensifier was also taken into account. Figure 8 provides a graphic illustration of the same information.

Table 4. Normalized Signal Currents and Range Increases of GEN3 AN/PVS-7 Over AN/PVS-5 and GEN2 AN/PVS-7 Under Various Illumination Conditions

NORMALIZATION: I(3,N,F) = 100 – FOLIAGE RELFECTION
I(3,N,F) = 100 – CONSTANT REFLECTION

% ILLUMINATION FROM			I(3,%N,F)	I(2,%N,F)	RANGE INCREASE		I(3,%N,C)	I(2,%N,C)	RANGE INCREASE	
FLUOR. LAMP	MERC. LAMP	NIGHT SKY			AN/PVS-7(3) AN/PVS-5	OVER AN/PVS-7(2)			AN/PVS-7(3) AN/PVS-5	OVER AN/PVS-7(2)
0	0	100	100	22.7	1.91	1.67	100	32.2	1.61	1.40
0	50	50	51	12.8	1.81	1.58	54.2	21.9	1.37	1.19
0	80	20	21.3	6.5	1.62	1.42	26.7	15.8	1.19	1.04
0	90	10	11.5	4.5	1.48	1.29	17.5	13.6	1.04	0.91
0	95	5	6.6	3.5	1.26	1.07	12.9	12.6	0.94	0.82
0	98	2	2.6	2.9	0.86	0.75	10.2	12.0	0.85	0.73
50	0	50	52.7	13.2	1.86	1.62	60.4	23.5	1.46	1.27
80	0	20	24.3	7.6	1.61	1.40	36.7	18.4	1.30	1.13
90	0	10	14.9	5.8	1.49	1.30	28.8	16.6	1.71	1.05
95	0	5	10.1	4.7	1.33	1.16	24.8	15.7	1.15	1.00
98	0	2	7.3	4.3	1.17	1.03	22.4	14.2	1.11	0.96

Table 5. System Parameters

	AN/PVS-5	AN/PVS-7	BAIRD	AN/AVS-6
T_{NO}	1.6	1.4	1.1	1.4
Tube S/N (Measured)	10-13	18-21	—	—
Number of Tubes	2	1	1	2
Generation	Second	Third	Second	Third
Noise Figure	1.6	2.0	1.6	2.0

It should be noted that the expected range increases shown are based on average cathode sensitivities for devices used in the Blossom Point test. The GEN2 image intensifiers have been in production for more than 10 years. During this time, the average cathode sensitivity has steadily but significantly increased and then leveled off. The GEN3 image intensifiers used in the test were from engineering development programs. An increase in the GEN3's sensitivity by a factor of 1.6 is expected. This will inherently increase its range performance by another factor of 1.2, resulting in a total range increase by a factor of 2.3 for the GEN3 AN/PVS-7 over the GEN2 AN/PVS-5 under natural, clear night sky illumination and foliage reflection (i.e., with no mixture of artificial light).

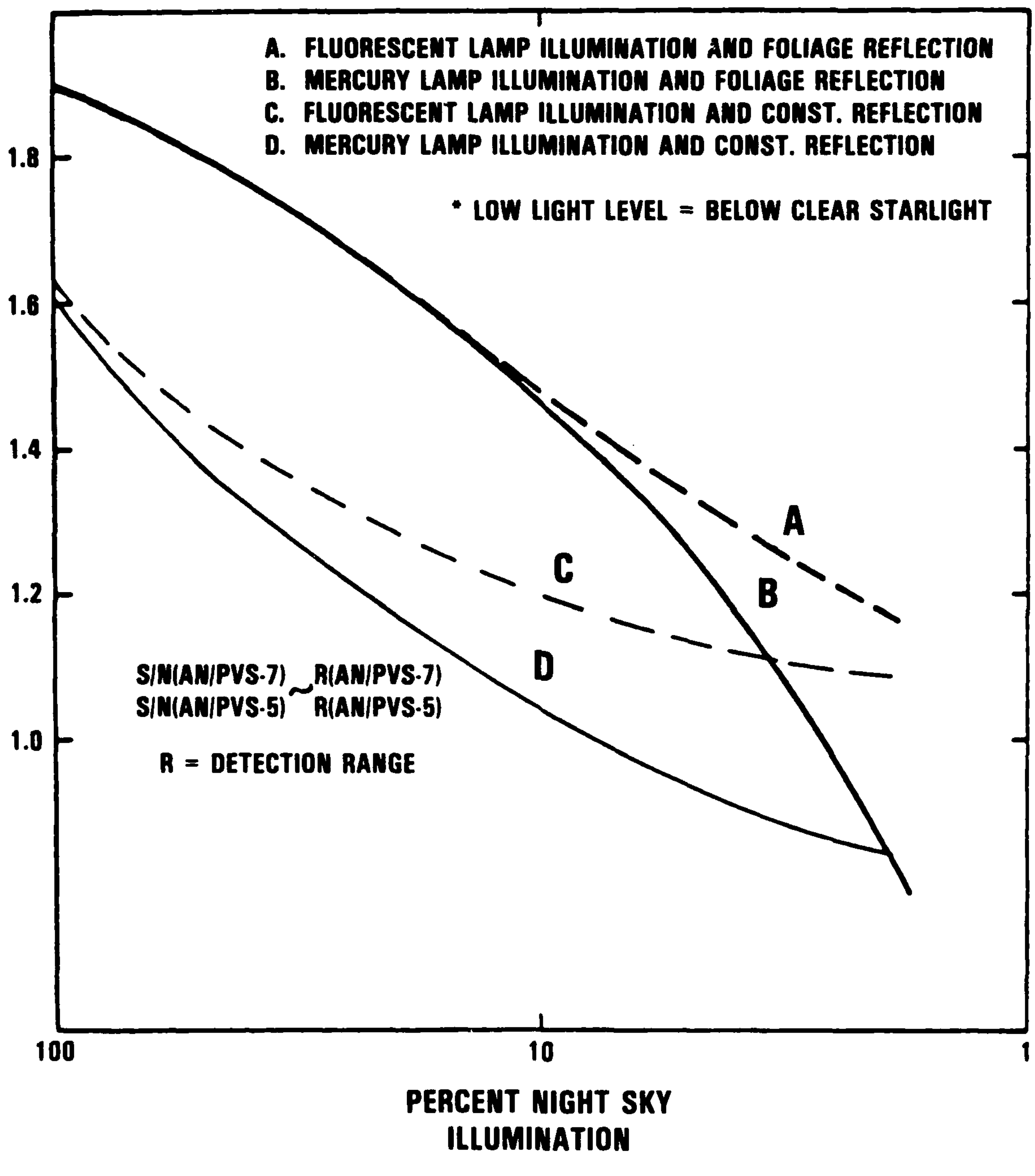


Figure 8. Low Light Level Range Increases of GEN3 AN/PVS-7 Over AN/PVS-5 as Function of Percentage of Night Sky

SECTION III. ANALYSIS OF THE BLOSSOM POINT, MD, FIELD TEST, JUNE/JULY 1984

The primary purpose of the Blossom Point field test was to compare GEN2 and GEN3 image intensifiers with respect to detection ranges of a man target. The image intensifier system used in this test together with main parameters are shown in Table 5. These systems include: AN/PVS-5, AN/PVS-7, AN/AVS-6, and Baird.

In the first part of the test during June 1984, the task was for a walking observer to detect a stationary man target. Variability in the test data was too diverse to draw conclusions. During tests on the same night and with the same equipment, detection ranges under medium contrast varied between 30m and 140m. The available data cannot confirm the reason for the large variability. Insufficiently trained observers and changing illumination conditions are suspected. Neither equal performance (as concluded by AMSAA[1]) nor any performance differences could be determined from this test.

For the second test during July 1984, better trained observers were used and the methodology was changed to detect a moving man target by a stationary observer. Two different test locations were used: an open grass field and a trail under a canopy. The target contrast under canopy could not be determined because of the low photopic light levels. While irradiance in photopic level could be measured, the radiance off of low reflectance targets could not.

Tables 6 and 7 show the day-by-day measured average detection ranges and the differences in detection ranges for various system combinations expressed in range ratios. Also shown are the ratios of detection ranges averaged over all days together with the average variation of these ratios. From a close examination of the range data for the open grass field, the following results were extracted:

1. A maximum increase in detection range of the GEN3 AN/PVS-7 over both GEN2 systems was observed during the night of the lowest photopically measured light level. This was also the night of the lowest cloud height.

2. The day-by-day variations in range ratios or differences in detection ranges for combinations of systems using the same technology are significantly smaller (2.5 to 2.7%) than the range ratio variations of systems with different technologies (9 to 18%).

3. The average differences in detection ranges for systems with the same technology are close to the expected value as follows:

   Baird: AN/PVS-5 expected 1.3, measured 1.2
   AN/AVS : AN/PVS-7 expected 1.0, measured 1.1

The increased detection range of the Baird system over the AN/PVS-5 is due to the difference in the input objective T-Numbers. The expected values are based on natural night sky illumination and no artificial contamination.

4. The average differences in detection ranges for systems with different technologies are significantly lower than the expected value as follows:

   AN/PVS-7: AN/PVS-5 expected 1.9, measured 1.3
   AN/PVS-7: Baird expected 1.5, measured 1.1

Table 6. Blossom Point Field Test Results

DETECTION OF MOVING MAN TARGET ON OPEN GRASS FIELD

DATE	PHOTOPIC LIGHT LEVEL AT 0100 (fc)	CLOUD COVER HEIGHT (km)	DETECTION RANGES (m) AN/AVS-6	AN/PVS-5	AN/PVS-7	BAIRD
25-26 July	3.6×10^{-4}	30-100 2-6	431 ±81	329 ±81	382 ±90	430 ±46
26-27 July	0.8×10^{-4}	100 1	—	223 ±29	384 ±20	256 ±44
27-28 July	5.0×10^{-4}	20-100 2.5-6	639 ±60	422 ±80	549 ±77	521 ±74
28-29 July	4.4×10^{-4}	10-40 4-6	636 ±85	540 ±76	591 ±73	632 ±62

DETECTION RANGE DIFFERENCES

DATE	AN/PVS-7 / AN/PVS-5	AN/AVS-6 / AN/PVS-5	AN/PVS-7 / BAIRD	AN/AVS-6 / BAIRD	AN/AVS-6 / AN/PVS-7	BAIRD / AN/PVS-5
25-26 July	1.16	1.31	0.89	1.00	1.13	1.31
26-27 July	1.72	—	1.50	—	—	1.15
27-28 July	1.30	1.51	1.05	1.23	1.16	1.23
28-29 July	1.09	1.18	0.94	1.00	1.07	1.17
Average All Days	1.32 ± 0.21 (16%)	1.33 ± 0.12 (9%)	1.10 ± 0.20 (18%)	1.07 ± 0.10 (9.3%)	1.12 ± 0.03 (2.7%)	1.22 ± 0.03 (2.5%)

Table 7. Blossom Point Field Test Results

DETECTION OF MOVING MAN TARGET UNDER CANOPY

DATE	PHOTOPIC LIGHT LEVEL AT 0100 (fc)	CLOUD COVER HEIGHT (km)	DETECTION RANGES (m) AN/AVS-6	AN/PVS-5	AN/PVS-7	BAIRD
25-26 July	1.2×10^{-5}	30-100 2-6	50.7 ±9.3	48.6 ±12.5	58.6 ±13.5	55.4 ±9.4
26-27 July	4.2×10^{-6}	100 1	55.8 ±7.2	45.4 ±9.8	62.2 ±11.7	—
27-28 July	1.8×10^{-5}	10-40 4-6	60.9 ±10.8	48.8 ±6.4	65.0 ±8.7	57.6 ±8.2

DETECTION RANGE DIFFERENCES

DATE	AN/PVS-7 / AN/PVS-5	AN/AVS-6 / AN/PVS-7	AN/PVS-7 / BAIRD	AN/AVS-6 / BAIRD	AN/AVS-6 / AN/PVS-5	BAIRD / AN/PVS-5
25-26 July	1.21	0.87	1.06	0.92	1.04	1.14
26-27 July	1.37	0.90	—	—	1.23	—
27-28 July	1.33	0.94	1.13	1.06	1.25	1.18
Average All Days	1.30 ± 0.06 (4.6%)	0.90 ± 0.02 (2.2%)	1.10 ± 0.04 (3.6%)	0.99 ± 0.07 (7.1%)	1.17 ± 0.09 (7.7%)	1.16 ± 0.02 (1.7%)

The detection range data under canopy shows the same trend, but not as distinct. Under canopy, significant differences in light levels were experienced over the range due to the differences in the density of the canopy. The above results can be explained and can be expected assuming the light illuminating the scene contained a large and varying amount of artificial lighting depending on meteorological conditions. Before interpreting the results, evidence based on measured photometric light levels and the meteorological data will be presented showing that the above assumption is correct.

Some cloud cover was usually present during the tests. Table 8 shows photometric light levels and percent of cloud cover for the nights of 28/29 June and 27/28 July. During these nights, the cloud cover changed considerably within a short period of time from a basically clear sky to close to 100% cloud cover at high altitude (6km). During both nights, the measured photopic light level nearly doubled when the clouds rolled in. Because clouds do not amplify light, the explanation is that the increase in the measured photopic light level was caused by artificial light from distant sources being reflected from the cloud layer.

Table 8. Photopic Light Levels for Various Meteorological Conditions Measured at Blossom Point, Summer 1984

DATE	TIME	LIGHT LEVEL (fc)	CLOUD COVER (%)	APPROXIMATE CLOUD (km) HEIGHT	REMARKS
28 June	2300	4.9×10^{-4}	100	3-6	
28 June	2345	4.6×10^{-4}	80	3-6	
29 June	0115	2.2×10^{-4}	30	6	Clear overhead
29 June	0130	2×10^{-4}	20	6	
27 July	2200	2.7×10^{-4}	10	6	
28 July	0100	5×10^{-4}	90	6	
28 July	0330	3.8×10^{-4}	40	3	

From the data available, the determination of the exact mixture of night sky and artificial light in the scene illumination was not possible. The only way to determine the spectral content of the scene illumination would have been to measure the spectral irradiance directly with a radiometer. This was not done at Blossom Point or any other field test. Also, due to the changing cloud cover and cloud height occurring on most nights, the mixture may be expected to vary considerably on any given night. Thus, test conditions on a given night may be very unstable. What can be done is to estimate the most likely mixture and its most likely variation based on the meteorological conditions as recorded during the Blossom Point test, and on cloud attenuation and atmospheric scattering coefficients found in the literature.

As a general rule,[2] a 75 to 100% cloud cover will attenuate the night sky light by a factor of 10, and a 38 to 63% cloud cover will attenuate by a factor of 3. A change from almost clear sky to full cloud cover was experienced on most nights giving a variation of 5 to 100% in the percentage of light from the night sky in the total scene illumination (Table 8). Table 4 and Figure 8 show that this will vary the expected range increase of the GEN3 AN/PVS-7 over the AN/PVS-5 from 1.91 down to 1.26 (foliage reflection and mercury or fluorescent lamp as artificial light).

What has not yet been taken into account is the scattering of the artificial light in the atmosphere. As shown in Figure 4, the light illuminating the scene consisted of attenuated light from the nigh sky (H_{N2}) and artificial light reflected from the clouds (H_{AS}). From the known amount of light reflected from the clouds and making reasonable assumptions on cloud reflections (40 to 70%) and the scattering coefficient for the existing humidity conditions at ground level and higher altitude,[9] the contribution of scattered light could be estimated to be 1×10^{-4} fc for clear sky or high cloud conditions. Using this estimate, the percentage of light from the true night sky can be as low as 2.5% for overcast conditions and high clouds (6km), and as high as 50% for a clear sky (Table 9).

Table 9. Photopic Composition of Light Illuminating Scene for Various Meteorological Conditions

Photopic Light Level at Scene

4×10^{-4} for overcast conditions

2×10^{-4} for clear sky conditions

H_{N1} (fc)	T_{CLOUD}	H_{N2} (fc)	H_{AR} (fc)	H_{AS}	$\frac{H_{N2}}{H_{N2} + H_A}$ (%)
1. a) 2×10^{-4}	1.0	2×10^{-4}	0×10^{-4}	0	100
b) 2	0.5	1.0	3.0	0	25
c) 2	0.3	0.6	3.4	0	15
d) 2	0.2	0.4	3.6	0	10
e) 2	0.1	0.2	3.8	0	5
f) 2	0.05	0.1	3.9	0	2.5
2. a) 1×10^{-4}	1.0	1×10^{-4}	0×10^{-4}	1×10^{-4}	50
b) 1	0.5	0.5	2.5	1	12.5
c) 1	0.3	0.3	2.7	1	7.5
d) 1	0.2	0.2	2.8	1	5
e) 1	0.1	0.1	2.9	1	2.5
f) 1	0.05	0.05	2.95	1	1.25

H_{N1} = Unattenuated starlight
H_{N2} = Starlight attenuated by cloud
H_{AR} = Artificial light reflected from cloud
H_{AS} = Artificial light scattered by atmosphere
T = Cloud transmission
H_A = $H_{AR} + H_{AS}$

Based on the meteorological data taken throughout the test, variations of this magnitude in the spectral content of the scene illumination are quite probable on every night with the exception of the night of 27/28 July, which will be discussed later. These variations in the illumination conditions will reduce the expected range ratio of the AN/PVS-7 to the AN/PVS-5 from 1.91 (no artificial light) to 1.81 for clear skies (with 50% artificial light), or will incur an actual decreased range performance of the AN/PVS-7 with a ratio of 0.86 with 98% artificial light (Table 4, foliage reflection, mercury lamp). For fluorescent lamp, the factors are 1.86 and 1.17, respectively. For the test at the grass field range, background reflections should be close to foliage reflection, whereas reflections at the canopy range are probably more constant with wavelength.

From the variances in the measured detection ranges (Table 6), the actual variations in the detection range ratios can be determined. For the range ratio of the AN/PVS-7 to the AN/PVS-5, these variations were as follows:

0.71 to 1.9 for the night of 25/26 July
0.94 to 1.8 for the night of 27/28 July
0.70 to 1.4 for the night of 28/29 July

These actual variations in detection ratios of 0.71 to 1.9 coincide with the calculated expected ratios of 0.86 to 1.86, and strongly suggest that a changing spectral distribution (due to the proximity of artificial sources) of the light illuminating the scene was the main factor causing these large variations in measured detection ranges.

The results extracted from the field test data are given below with explanations of why these results (Table 6) should have been expected.

1. A maximum increase in detection range of the GEN3 AN/PVS-7 over the GEN2 AN/PVS-5 was observed on the night of 26/27 July. During the night, the lowest photopic light level was recorded but, more important, the cloud cover was always 100% and cloud heights stayed consistently below 1km, significantly lower than all the other nights. With such a low cloud level, the amount of artificial light reaching the clouds and being reflected to the targets should be much lower. The closest major source of artificial light was from the town of La Plata, MD, about 15km away from the test site. The consistency of the meteorological conditions during this night also decreased the variance in the measured detection range by more than a factor of 2 compared to the other nights. The range ratio of AN/PVS-7 to AN/PVS-5 during this night varied between 1.4 and 2.1. This strongly supports the previous assumption that variations in the detection ranges are, to a large degree, due to changing the illumination conditions (i.e., changing mixture of artificial light with the night sky).

2. Day-by-day variations in detection range ratios are significantly smaller for systems of the same technology than for systems of different technologies. This is to be expected, as the spectral sensitivities or bandpass of the detector is basically the same for all GEN3 systems, likewise for

all GEN2 systems. Therefore, a change in the composition of the scene illumination will change the responses of systems of the same technology by the same amount. A comparison of systems with different spectral responses, such as GEN2 and GEN3 (Figure 2), changes in the composition will produce different changes in the response.

3. The average detection range ratios between systems with the same technology are close to the expected values.

4. The average detection range ratio between systems with different technologies are significantly lower than the expected values.

The results of 2, 3, and 4 above again strongly suggest that changing illumination conditions (mixture content) had a much stronger influence on the variation in detection ranges than did observer variability. For example, the computed detection range for the AN/PVS-7 when conditions change from overcast to clear sky (Table 4), with 50 to 98% artificial light, varies by a factor of 4.4 ($=\sqrt{51/2.6}$). The detection range of the AN/AVS-6 will change by the same factor, but for the AN/PVS-5 and the Baird system, the factor is only 2.1. Figures 9 and 10 show the change in detection ranges as a function of the composition of the scene illumination for foliage and constant reflection for the AN/PVS-5 and the GEN3 AN/PVS-7.

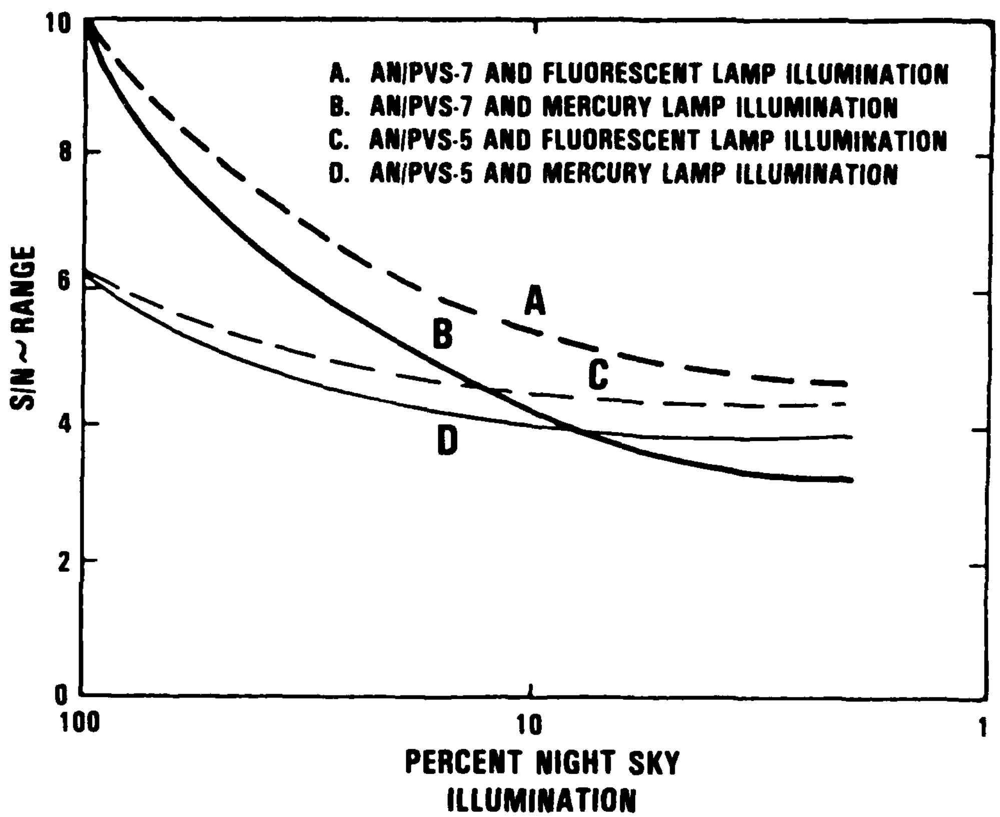


Figure 9. Normalized S/N Ratio as Function of Percentage of Night Sky for Constant Reflection

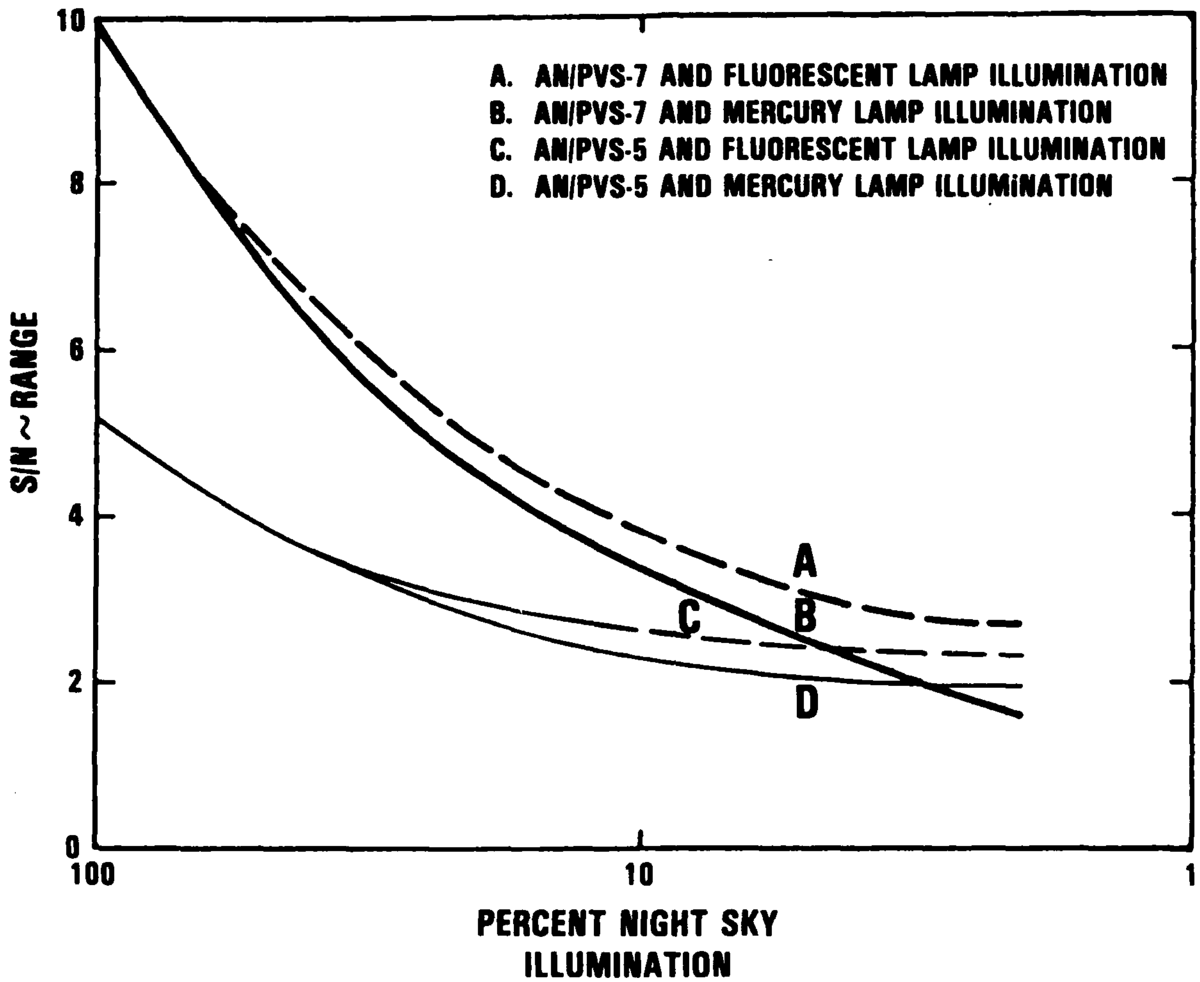


Figure 10. Normalized S/N Ratio as Function of Percentage of Night Sky for Foliage Reflection

Discounting observer variability, it can now be concluded by comparing expected range increases (Table 4) with observed range increases (Table 6), that on all nights (except 26/27 July) the average scene illumination contained less than 10% light, measured in photopic units, from the true night sky. The remaining 90% (or more) of the light had its origin from artificial sources. This is certainly not the condition where image intensifiers are expected to be used in any real conflict.

SECTION IV. CONCLUSIONS

Data from field tests conducted during the past several years to determine performance differences between GEN2 and GEN3 image intensifier devices show little or no differences in performance. This report demonstrated that, as the amount of illumination from artificial sources near the test sites increases, the performance of GEN2 and GEN3 image intensifier systems tended toward equality. An analysis of the meteorological conditions and the photometric light level data taken during the Blossom Point field test provided evidence that a considerable but widely varying amount (50 to 98%) of the photopic scene illumination did not originate from the natural sky, but from shopping centers, towns, and other streetlights—not the conditions that would be present during an actual conflict. It can be concluded that variations in the mixture content of the scene illumination such as described are a primary cause for the large differences in measured detection ranges under presumably equal conditions; that is, equal conditions of photopically measured light levels. Photopic light levels only have meaning where the human eye is the sole detector to be evaluated. For the evaluation of other detectors, the use of photopic light levels to measure the scene illumination can be zero fc, but seen perfectly in all details with a GEN3 image intensifier. On the other hand, a situation can occur where even a large amount of fc will not light up the intensifier (e.g., the blue/green instrumentation lights of a helicopter). A method for resolving this confusion and misinterpretation is to abandon the fc and measure the scene illumination in radiometric units ($W\ cm^{-2}\ \mu m^{-1}$, not lumen(s) ft^{-2}).

This report cited the Blossom Point field test as an example for analysis. During one night of the Blossom Point test, meteorological conditions existed (heavy clouds below 1km) that consistently limited the amount of artificial light from the night sky to between 50 to 80% of the total light. On that night, variations in the measured detection ranges were smaller than on other nights, and the range increase of the GEN3 AN/PVS-7 over the GEN2 AN/PVS-5 was, as expected, a factor of 1.7 (Tables 4 and 6). It is suspected that similar or even worse conditions have also existed during other field tests. However, lack of data on cloud cover, cloud height, and humidity prevents any analysis of these tests.

SECTION V. RECOMMENDATIONS

For future field comparisons of GEN2 and GEN3 image intensifiers, a test site must be found where the influence of artificial light in the scene illumination is minimal—no artificial light at all is preferred, but hard to find under peacetime conditions. The amount of artificial light that might be tolerable can be determined from Table 4 or Figures 6 through 10. The suitability of a test site has to be determined through the measurement of the spectral irradiance (W cm^{-2} μm^{-1}) with a radiometer. During the test, the spectral irradiance must be monitored constantly.

The conditions of any test have to be carefully analyzed when time required to complete a specific task is used to evaluate the performance of a system. As pointed out in the example for changing a fan belt in an APC, many of these tasks can be performed at light levels ranging over many orders of magnitude with the same efficiency or within the same time period. However, the range of light levels where differences between GEN2 and GEN3 intensifiers can be expected is less than one order of magnitude and should be near or below clear starlight conditions.

Finally, the system-unique differences should be eliminated. For a fair comparison test of intensifier technology, the same system should be used with the only difference being the utilization of a GEN2 or a GEN3 image intensifier.

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